Understanding Moraine Formation Around the Muldrow Glacier, Denali National Park and Preserve

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Introduction

Recent climate change models show that Alaska is likely to see the effects of climate change at faster rates than mid-latitude areas, such as the lower-48 states *(IPCC 2007)*. To understand how climate change will affect geologic systems, we find clues about how geologic systems responded to past climate changes by examining glacial geologic records. Denali National Park and Preserve (Denali) is an example of a heavily glaciated area that contains such clues. In Denali, the sediments and landforms that glaciers produce record the nature and timing of past climate changes, and they hold the key to helping predict Alaska's future climate.

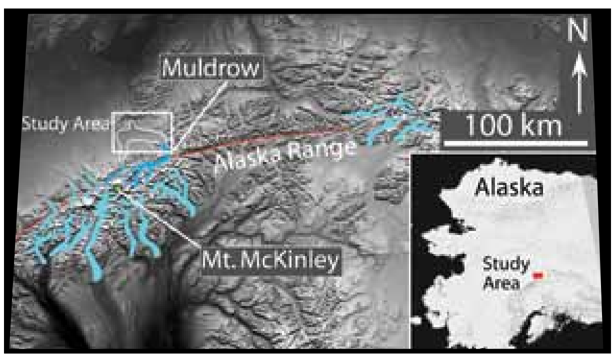


Figure 2. IKONOS satellite image of the Wonder Lake area, showing the McKinley River, the extent of glacial stages and sample locations (modified from Werner and Child 1995). Note that moraine X (green) and moraine Y (light blue) are two of many moraines in the area.

Image courtesy of IKONOS

Figure 1 (Left). Dr. Lewis A. Owen taking a photograph of a boulder surface that was sampled for this study.

Photograph courtesy of Dr. Jason Dortch

Glaciers are sensitive markers of current and past climatic conditions, mainly temperature and precipitation. Changes in temperature and precipitation alter the size and position of a glacier. Cooler temperatures combined with increased snowfall will cause a glacier to advance, whereas warmer temperatures and/or decreased snowfall will cause a glacier to thin and retreat.

The glaciers in Denali were considerably larger in the past than they are today *(Figures 2-3)*. When glaciers melt they leave behind ridges of debris called moraines that can be used to reconstruct their former positions *(Figure 3a)*. The McKinley River area contains several moraines left by Muldrow Glacier. These moraines are used as a standard to compare the timing of glaciation in other regions of Alaska *(Reed 1961, Ten Brink and Waythomas 1984) (Figure 2)*.

Historically, radiocarbon dating and lichenonmetry (measurement of certain lichens that increase in size at a constant rate every year) were used to determine the ages of glacial landforms in the McKinley River area *(Bijkerk 1980, Werner 1982)*. These techniques can only be used to date organic material younger than ~50,000 years. Since much of the glacial debris and landforms are devoid of organic material and may be older than 50,000 years old, these techniques will not work. A relatively new method, cosmogenic radionuclide dating, can be used to obtain ages on glacial debris and landforms from 100 to over 1 million years old. The secondary neutron cascade produced by galactic cosmic rays (mostly hydrogen atoms stripped of their electrons) penetrates Earth's atmosphere and bombards the uppermost rock surfaces causing nuclear reactions in the atoms comprising the rocks. Beryllium-10 (^{10}Be), in particular, is produced from oxygen and silica in the rock. The ^{10}Be production rates are known. By determining the amount of this radionuclide in a sample, we can calculate how long that rock has been sitting on the surface of Earth.

However, there is a catch. Beryllium-10 dating of moraines that are less than 10,000 years old may give younger ages than radiocarbon or lichenonmetry ages from the same landform. This occurs because the methods are dating different stages of moraine development. For example, if a rock on a moraine rolls over, a new rock surface that has not accumulated ^{10}Be will be exposed. Sampling this new surface can give ages that are too young. In Alaska, many of the moraines have a core of ice that melts slowly and causes the boulders on the surface to roll. Cosmogenic dating

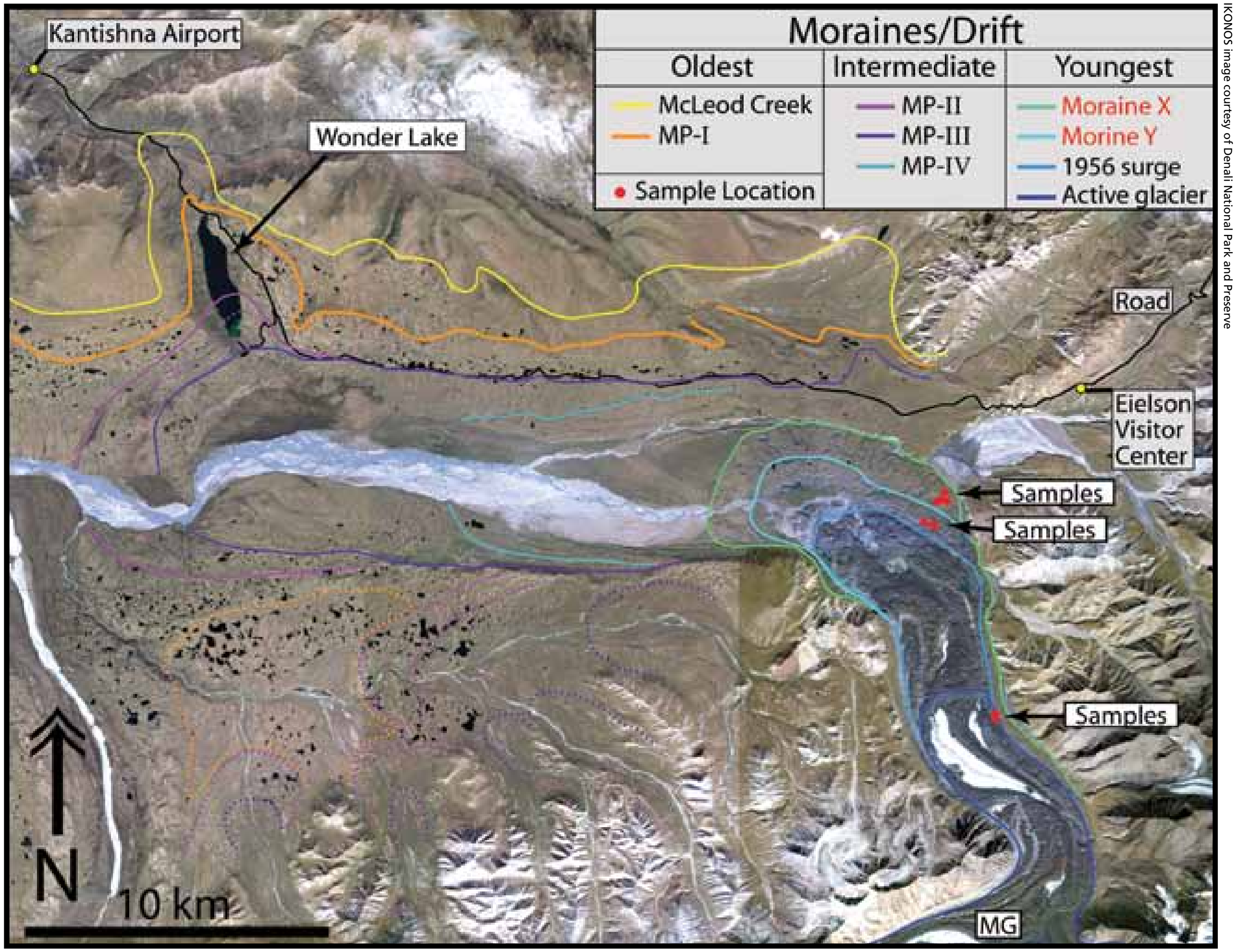


Figure 3. IKONOS satellite image of the Wonder Lake area, showing the McKinley River, the extent of glacial stages and sample locations (modified from Werner and Child 1995). Note that moraine X (green) and moraine Y (light blue) are two of many moraines in the area.

determines the stabilization age of glacial landforms, when the ice core has melted. Other dating techniques such as radiocarbon dating and lichenonmetry give the age of when the glacial debris was first deposited.

Many of problems associated with ^{10}Be dating have been addressed in numerous studies *(Balco et al. 2009, Gosse and Phillips 2001, Hallet and Putkonen 1994, Owen et al. 2008, Putkonen and Swanson 2003, Putkonen and O'Neil 2005)*; however, the time lag between deposition and stabilization of moraines has received little attention *(Briner et al. 2005)*. Quantifying the time lag between deposition and stabilization is essential for understanding and comparing recent fluctuations in glaciation that are driven by climate change.

Purpose and methods

The primary issue we are exploring on the northern side of the Alaska Range is the lag time between deposition and stabilization of moraines. A key clue is whether unstable moraines have near zero ^{10}Be ages. To assess these two issues we refer to two test moraines, referred to here as moraine X and moraine Y.

The deposition age of moraine X has already been defined through lichenometry, so we can quantify the time lag between moraine X's deposition and stabilization using ^{10}Be dating. The time between moraine stabilization and moraine deposition is determined by subtracting the ^{10}Be age from the lichen age.

The second issue is explored in moraine Y. Werner *(1982)* argued that moraine Y is unstable and the active ice is by definition "unstable". If our hypothesis is correct, then unstable landforms should yield a zero ^{10}Be age.

Data gathering and research involved remapping the extent of moraines previously mapped by Werner *(1982)* in the McKinley River area using field methods, aerial photography, and IKONOS satellite imagery, provided by Denali National Park and Preserve. Samples for ^{10}Be dating were collected by chiseling small amounts of rock from the upper 1 to 2 inches (2.5-5 cm) of large granitic boulders on moraines. Multiple samples on each landform enabled statistical analysis of age populations as well as further examination of landform stabilization processes.

The rock samples were subjected to a series of chemical leaches, dissolution, and chemical separations to isolate the Be atoms. Measurements of the separated ^{10}Be atoms were obtained using an accelerated mass spectrometer at the Purdue Rare Isotope Measurement Laboratory at Purdue University. The number of measured ^{10}Be atoms is divided by the rate at which they accumulate in rock surfaces to yield an exposure age. The exposure age tells us how long the boulder's surfaces have been exposed to cosmic rays on Earth's surface.

Moraine ages

Moraine X

Moraine X is about 1 mile (1.6 km) wide, and is stable with no evidence for active slumping or exposed ice walls *(Werner 1982) (Figures 3, 4b)*. Seven samples were collected from six boulders for ^{10}Be dating.

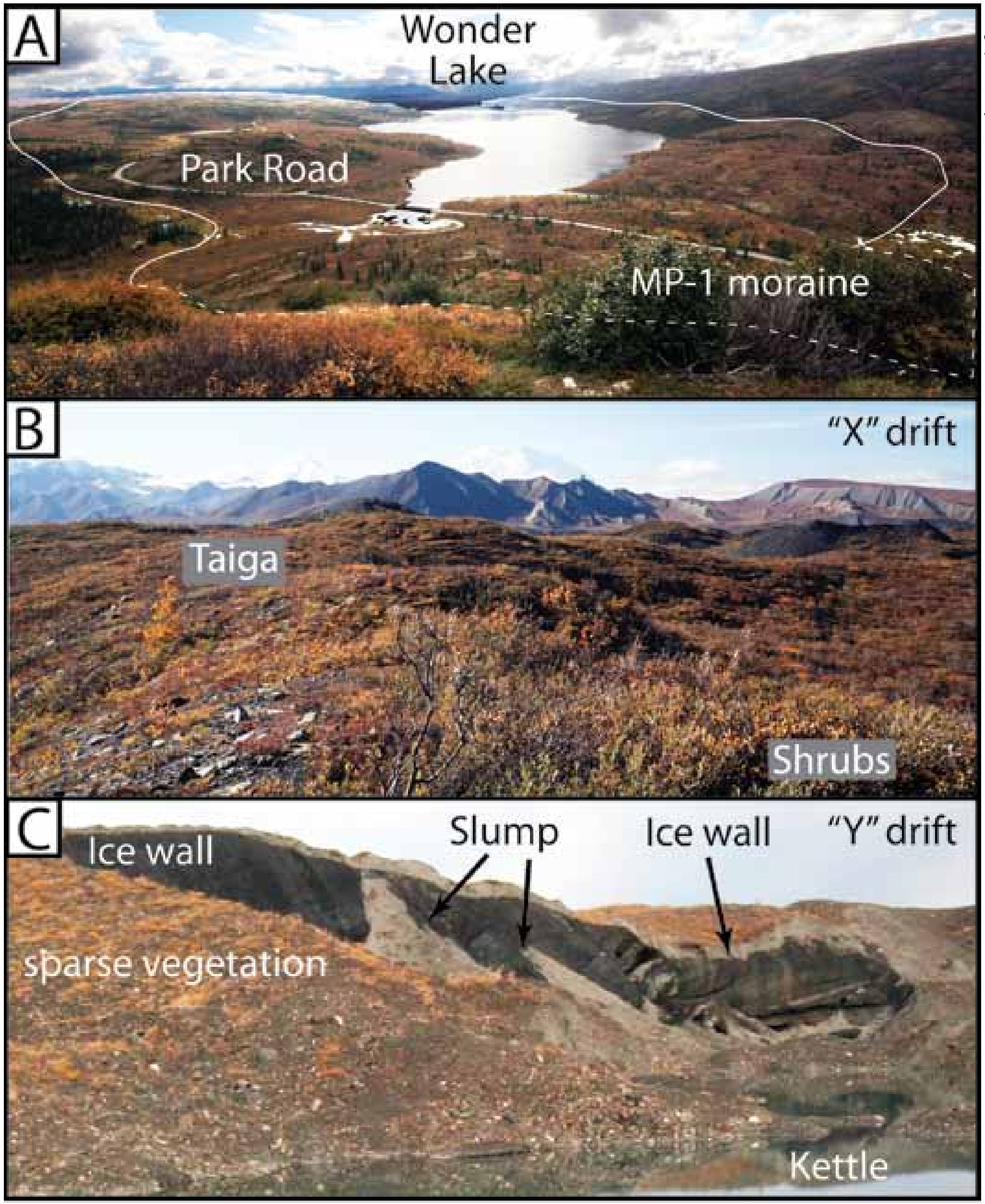
Statistical analysis of ^{10}Be ages revealed a strong grouping of ^{10}Be ages at 540 years. This age is interpreted to represent the stabilization of moraine X. The difference between the lichen age (>1,800±100 years) *(Werner 1982)* which represents moraine deposition and the ^{10}Be age which represents moraine stabilization (540 years) is the time lag between moraine deposition and stabilization (1,260 years).

While the lag time is not significant in relating glacial sediment that are >100,000 years old, it could have adverse affects on comparison of young moraines (< 10,000 years old), and between areas using mixed chronology techniques, such as radiocarbon, lichenometry, and dendrochronology. This is particularly important for studies focused on recent climate change. For example, if several moraines were determined to be 2,700 years old, some dated using lichenometry and others using ^{10}Be, then comparing the extent of glaciation based on moraine ages would be inappropriate. The moraines dated using ^{10}Be may in fact be 1,300 years older (i.e. were actually deposited 4,000 years ago but stabilized 2,700 years ago), which would alter estimates of glacial retreat and provide an incorrect estimation of the 2,700 year old Neoglacial extent to climate modelers.

Moraine Y

Moraine Y ranges from 0.25 to 1.25 miles (0.4-2.0 km) wide *(Figure 2)*. Werner *(1982)* argued that moraine Y is unstable based on the presence of active slumping, streams originating from outcrops, and several outcrops of glacial ice *(Figure 3c)*. We concur with this view. Four samples were collected from four boulders for ^{10}Be dating.

The ^{10}Be ages did not pass statistical analysis. This



Photographs courtesy of Dr. Jason Dortch

Figure 4. (Right) Views of recent moraines: A) looking south at Wonder Lake and the hummocky MP-1 ground moraine; B) view of moraine X; C) view of moraine Y ice core. Dense taiga and tundra cover all stable moraines making their morphology difficult to see. Dashed lines mark glacial limits obscured by vegetation or distance.

was expected because moraine Y is unstable; the ^{10}Be ages should be close to zero and not cluster together. The ^{10}Be ages provide insight into the stabilization process. The age of moraine Y was estimated at 900 years using lichenometry *(Werner 1982)*. Three boulders have a zero ^{10}Be age, which confirms our hypothesis that boulders very likely move as the ice core melts out and the moraine stabilizes. One ^{10}Be age was almost twice as old as the lichen age, which tells us that prior ^{10}Be accumulation occurred when the boulder surface was still part of Mt. McKinley or when the boulder was carried on top of Muldrow Glacier. This boulder will likely be broken and rolled during the stabilization period, which will eventually reset the ^{10}Be age to zero.

Active ice

The active Muldrow Glacier is mainly covered by thick debris on its surface (supraglacial debris). There is also bare glacial ice, exposed ice walls, and small kettle lakes. Samples collected from boulders on active ice should have a zero ^{10}Be concentration because they have only been recently exposed. Four boulders were sampled for ^{10}Be dating from the active glacier to check for prior ^{10}Be accumulation.

Three of the ^{10}Be ages on the active Muldrow Glacier are within error of a zero age, which confirms our second hypothesis that boulders will very likely move again as the ice core melts out and the moraine stabilizes. One sample, with an age of 1,900 years, has significant prior ^{10}Be accumulation. This one boulder will likely be broken and rolled during the stabilization period, which will eventually reset the ^{10}Be age to zero. As with moraine Y, the importance of ^{10}Be accumulation before moraine stabilization appears to be minimal.

Conclusions

Only two ^{10}Be ages, one each from moraine Y and the active ice, have prior ^{10}Be accumulation on boulder surfaces. This is likely due to the continued toppling, exhumation, and break up boulders experience during glacier transport and moraine stabilization. This shows that ^{10}Be ages are reset to “zero” until a moraine stabilizes, which confirms our second hypothesis that ^{10}Be dating records a moraine’s stabilization age.

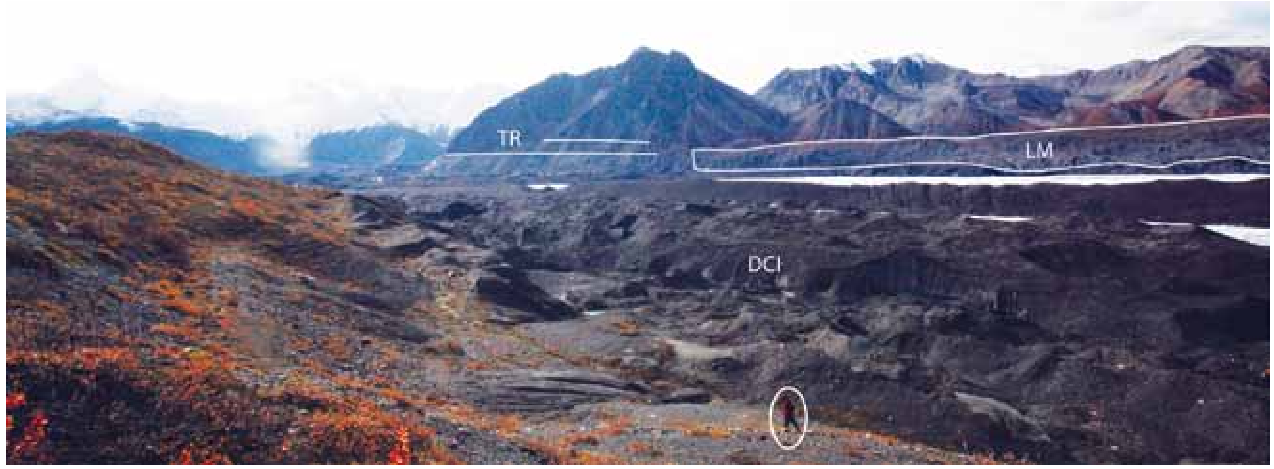


Figure 5. View of the Muldrow Glacier with common glacial features labeled. Note the person in the white oval for scale. TR are glacial trim lines; LM is a lateral moraine; and DCI is debris covered ice.

Moraine X has an average ^{10}Be age of 540 years old. Using the lichen age (1,800 years old) shows that the lag time between landform deposition and stabilization is 1,260 years. Therefore, we argue that moraines with an ice core can take approximately 1,300 years to stabilize after initial deposition, although this might vary in different climatic settings. Stabilization times need to be quantified in different climatic regimes to build a model relating landform stability and ^{10}Be ages and determine if the lag time is consistent in both upper and lower latitude areas.

This study provides a preliminary framework for determining stabilization lag time. This data will help enable a clear understanding and more accurate comparison of ^{10}Be ages (less than 10,000 years old) with other dating methods. Our results suggest that correlation of glacial deposits less than 10,000 years old dated with different methods will need to be reevaluated. Incorrect correlation of glacial deposits will have a significant effect on climate models, as the models need to compare changes in the position and size of glaciers over large areas that occurred at the same time. If the correlations are incorrect, the models will yield inaccurate results. Future work focused on refining the lag time between moraine deposition and stabilization will enable more accurate ages and climate driven changes in glaciation to be more narrowly defined and better understood.

The results of our studies have been published in Dortch et al. *(2010a and 2010b)*.

We would like to thank the Murie Learning and Science Center for funding this project. Sadly, our co-author, Phil Brease, passed away on May 12, 2010. He was a kind person, interested in the processes that shape our planet . He will be greatly missed by all.

Photograph courtesy of Dr. Jason Dortch

Figure 6. View of the Muldrow Glacier. The active ice ends just right of the photo. Notice the large volume of rock debris that covers the active glacier.

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